Institution: The University of Manchester		
Unit of Assessment: 12 (Engineering)		
Title: Providing the scientific foundations to grow a sustainable, low-carbon UK bioenergy sector		
Period when the underpinning research was undertaken: 2012 – 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (*e.g.* job title):**	**Period(s) employed:**
Andrew Welfle	PDRA 2014–2019, Research Fellow 2019–present	2011–present
Patricia Thornley	Reader 2003–2015, Professor 2015–2018	2003–Sep 2018
Mirjam Röder	PDRA 2010–2016, Research Fellow 2016–2018	2010–Sep 2018
Paul Gilbert	PDRA 2009–2010, Lecturer 2010–2018	2009–Apr 2018
Period when the claimed impact occurred: May 2014 – July 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Bioenergy has become the largest renewable energy technology in the UK, contributing >31% renewable electricity, >83% renewable heat and 5% total transport energy. The UK Government has strong ambitions to increase bioenergy as part of its industrial strategy and climate change commitments.

University of Manchester (UoM) research has provided science underpinning the UK's bioenergy strategy, which provides the foundations for growing a sustainable bioenergy sector. Working in partnership with industry, NGOs and Government, UoM research has promoted a greater role for bioenergy, use of UK biomass resources, and best use for biomass. Manchester's science directly influenced the refocusing of the UK's Renewable Heat Incentive (RHI) in 2015 to prioritise heat bioenergy generated from UK waste materials that has, to date, resulted in an 84% increase in UK bioheat generation from these fuels. Manchester research also helped secure an additional GBP110,000,000 from HM Treasury to extend the RHI scheme and develop future renewable heat support schemes.

2. Underpinning Research

The bioenergy research themes described here were pioneered at UoM through the Supergen Bioenergy Hub (led by Thornley at UoM between 2012–18, and at Aston University from September 2018 onwards): the UK's bioenergy research programme and network that brings together academia, industry, government and societal stakeholders to develop sustainable bioenergy systems. UoM research has influenced the UK's Bioenergy Strategy through: i) promoting a greater role for bioenergy, ii) promoting UK biomass resources, and iii) promoting the best uses for biomass.

Identifying the UK's bioenergy opportunities

Between 2012 and 2014, Welfle developed the 'Biomass Resource Model' (BRM), a tool that allows evaluation of the availability of biomass resources through analysing land systems, industries and supply chains within a chosen geography. Previous models of this type overwhelmingly focused on assessing specific biomass supply chains (*e.g.* energy crops), specific technologies (*e.g.* gasification systems) or specific locations (*e.g.* a single field or region). The BRM is novel in allowing a full assessment of all land-sourced biomass resources and all bioenergy technology options, with the flexibility to potentially analyse any chosen geography.

The BRM provided the foundation for a series of papers that both analysed the biomass resource dynamics in key countries from which the UK is/could import biomass for energy **[1]**; and identified indigenous biomass resource opportunities the UK could pursue to reduce reliance on imported biomass **[2]**. Key outputs from this research included:

- **Competition for biomass is only likely to intensify for countries like the UK**, which are increasingly reliant on imported biomass for energy. Further constraint may also

emerge if key biomass exporting countries, such as Brazil, were to increase use of biomass for energy rather than export, affecting global biomass trade markets **[1]**.

- **Promoting UK biomass resources**: There are significant indigenous biomass opportunities in the UK including from agriculture, forestry and industry residue resources, waste resources, and through promoting production of energy crops. UK indigenous biomass resources could service up to 44% of UK energy demand by 2050, reducing reliance on imports **[2]**.
- **Promoting the best uses for biomass**: Selected UK biomass resources should be prioritised to produce high-value products such as transport fuels. The remaining suitable resources should be dedicated to generating heat energy **[2]**.

Increasing the Greenhouse Gas (GHG) performance of bioenergy
Since 2012, UoM have developed pioneering research and methods applying life cycle assessment (LCA) analyses to evaluate the GHG performance and sustainability of bioenergy systems. This is underpinned by the research of Thornley *et al.* **[3]**, who conceptualised how to best use LCA to validate bioenergy projects that deliver GHG reductions compared to fossil fuel energy systems. Through assessing the GHG performances of each life cycle step within a given bioenergy system, strategic choices can be made about the inclusion of processes inherent to bioenergy technologies and their supply chains.

Röder *et al.* **[4]** analysed the GHG performances of the UK's current strategy of large-scale bio-power generation from wood pellets imported from North America. They found this practice could deliver energy with emission performances of between 80% less GHGs, to 70% more GHGs than fossil fuels. By analysing each step in the process life cycles, they identified specific practices that should be avoided to ensure less GHG generation compared to fossil fuel systems.

UoM bioenergy research applied for the UK Government
Welfle completed a knowledge exchange secondment from UoM to the UK Department of Energy and Climate Change (DECC) in 2014, contributing to DECC's highly influential 'Bioenergy Emissions and Counterfactual' (BEaC) research that evaluated the GHG performance of bio-power options for the UK **[A]**. Welfle evaluated further options for the UK increasing bio-heat generation by applying UoM's BRM analysis tool to identify suitable UK biomass resource opportunities, and UoM's bioenergy GHG LCA approach to evaluate the GHG performance of each. The resulting research paper **[5]** and technical report for DECC **[6]** presented key recommendations:

- The vast majority of the 2,000 UK bioheat scenarios analysed *"demonstrate significant potential GHG savings compared to conventional fossil fuel generation"* achieving GHG performances far below the UK's benchmark for sustainable generation (34.8 $gCO_2e\ MJ^{-1}$) **[5]**.
- Food and agricultural wastes and residues that have no other uses should be prioritised for bioenergy. These represent examples of 'bioenergy opportunities' for generating low/net-zero carbon energy, contributing to the decarbonisation of the UK energy sector and wider GHG emissions inventories, as counterfactual waste management emissions are prevented **[5]**.

3. References to the research

The impact in this case study is built on research themes developed at UoM and underpinned by the following research outputs. Paper **[3]** won the Elsevier Atlas Award. References **[5]** and **[6]** were produced in collaboration with DECC as part of a knowledge exchange secondment. UoM authors are highlighted in bold text. Citations are from Scopus, and accurate as of 6 March 2021.

[1] Welfle A J. "Balancing Growing Global Bioenergy Resource Demands - Brazil's Biomass Potential and the Availability of Resource for Trade." *Biomass & Bioenergy*. **2017**, Vol 105, p. 83-95. DOI: 10.1016/j.biombioe.2017.06.011 (46 citations)

[2] Welfle A J, **Gilbert P**, **Thornley P**. "Securing a Bioenergy Future without Imports." *Energy Policy*. **2014**, Vol 68, p. 1-14. DOI: 10.1016/j.enpol.2013.11.079 (39 citations)

[3] Thornley P, **Gilbert P**, Shackley S, Hammond J. "Maximizing the Greenhouse Gas Reductions from Biomass: The Role of Life Cycle Assessment." *Biomass & Bioenergy*. **2015**, Vol 81, p. 35-43. DOI: 10.1016/j.biombioe.2015.05.002 Winner of Elservier Atlas Award. (70 citations)

[4] Röder M, Whittaker C, **Thornley P**. "How Certain are Greenhouse Gas Reductions from Bioenergy? Life Cycle Assessment and Uncertainty Analysis of Wood Pellet-to-Electricity Supply Chains from Forest Residues." *Biomass & Bioenergy*. **2015**, Vol 79, p. 50-63. DOI: 10.1016/j.biombioe.2015.03.030 (76 citations)

[5] Welfle A J, **Gilbert P**, **Thornley P**, Stephenson A. "Generating low-carbon heat from biomass: Life cycle assessment of bioenergy scenarios." *Journal of Cleaner Production*. **2017**, Vol 149, p 448-460. DOI: 10.1016/j.jclepro.2017.02.035 (34 citations)

[6] Welfle A J, **Gilbert P**, **Thornley P**. "Greenhouse Gas Performance of UK Biomass Resources for Heat Bioenergy Pathways." Technical Report Produced for the UK Department of Energy & Climate Change. University of Manchester. **2015**.

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- EPSRC Impact Acceleration Funding through UoM & match funding from UK DECC (IAA-047 - GBP68,526), supporting Welfle's secondment to DECC (01/05/14 to 31/11/14, awarded to Gilbert at UoM).
- EPSRC Grant (EP/P024823/1 - GBP756,074) supporting the Supergen Bioenergy Hub Extension (01/08/17 to 30/09/18, awarded to Thornley at UoM).
- EPSRC & BBSRC Grant (EP/S000771/1 - GBP5,100,084) supporting the Supergen Bioenergy Hub (01/11/18 to 31/10/22 - proposal developed at UoM by Thornley, who moved to Aston University in Sept 2018). Welfle contributed to the development of the research programme and is a current Supergen Co-Investigator at UoM.

4. Details of the impact

UoM researchers have worked closely with Government departments and advisory organisations providing science and recommendations to promote i) a greater role for bioenergy, ii) greater utilisation of UK waste and residue resources, and iii) bio-heat as a best use for UK biomass. The following examples demonstrate areas where UoM research has influenced UK bioenergy strategy and policy:

Influencing UK bioenergy strategy

UoM researchers contributed to, and are cited by, over 20 reports advising the UK Government on the development of the UK bioenergy strategy. A prominent example includes the Committee on Climate Change's (CCC) 'Biomass in a Low-Carbon Economy' Report **[B]** – developed to advise the Government of the potential role of bioenergy in decarbonising the UK economy. CCC's Head of Bioenergy corroborates **[C]** that UoM research was integral to develop the CCC's recommendations for Government:

- "…*Thornley had a key role in developing the Report through leading the Expert Advisory Group"* **[C]**.
- The Report's scientific framework was developed based on a UK-wide 'call for evidence' consultation process - *"University of Manchester research focusing on biomass resource availability and GHG performances of bioenergy authored by* [UoM researchers] *was widely cited and referenced in key responses to this consultation, included within the consultation responses from the National Farmers Union, Ricardo Energy & Environment Consultants, UK Renewable Energy Association..."* **[C]**.
- UoM research **[2, 3, 5]** is cited throughout the CCC's Final Report **[B]** and the Bioenergy Call for Evidence Report **[D]**.

The CCC Report's recommendations directly influenced UK Government Bioenergy Strategy as evidenced in the Government's 'Clean Growth – Transforming Heating' Report **[E]**. CCC

recommendations on the potential scale of bioenergy that may be generated from UK biomass resources are cited – these draw directly on UoM research. Two examples include:

i) *"*[CCC] *indicates that sustainable supply could meet 5-15% of the UK's primary energy demand"* almost directly quotes the findings from **[2]**, *"residues from agriculture, forestry and industry* […] *potentially providing up to 6.5% of primary energy demand by 2050. Waste resources are found to potentially provide up to 15.4%".*

ii) *"It is necessary to prioritise biomass where it has the greatest decarbonisation impact"* directly draws on the findings from **[5]** *"*[policy focus] *should move away from the focus of bioenergy to 'maximise renewable generation' rather than to simply 'reduce GHG emissions'".*

UK Research Councils acknowledged this change in UK Bioenergy Strategy, as demonstrated through the GBP8,000,000 EPSRC 2019 'Decarbonising Heating and Cooling' funding call **[F]**, which directly cites the Government's 'Transforming Heating' Report **[E]**.

Influencing UK bioheat Renewable Heat Incentive (RHI) policy

During 2014 Welfle was seconded to UK DECC, where he applied UoM research to analyse the GHG performance of UK heat bioenergy scenarios using UK resources. BEIS' Head of Bioenergy & Land Use Science confirms that this, *"…project was carried out working closely with DECC's Renewable Heat Incentive (RHI) Policy Team, where the research fed directly into their work in refocusing the RHI scheme particularly around anaerobic digestion"* **[G]**.

Prior to its refocusing in 2015, the RHI scheme supported heat from biogas produced using any form of biomass as fuel. The UK Government decided to review this to *"maximise the benefits of payments to contribute to carbon budgets"*, proposing to *"reduce or eliminate support for new installations relying on crops as their primary feedstock"* **[H]**.

Recommendations from Welfle's research influenced the RHI Policy Criteria, notably regarding the greater incentivisation of food and agricultural wastes - based on their potential for greater decarbonisation of the UK's waste and agriculture GHG inventories:

- Biogas schemes eligible for unlimited support include those fuelled by *"…feedstocks that are currently exempt from demonstrating sustainability criteria such as manure, slurry and food waste"* **[H]**. This links directly to UoM recommendations **[5, 6]**: *"…agricultural wastes currently managed utilising GHG intensive processes should be prioritised for bioenergy pathways"* and *"food wastes currently sent to landfill should also be prioritised for bioenergy pathways".*
- The refocused RHI prioritises these biogas schemes, as *"…these tend to provide more cost effective carbon abatement, with significant additional emissions savings in the waste and agriculture sectors"* **[H]**. This links directly to UoM recommendations **[5, 6]**: *"Utilisation of these wastes* via *'anaerobic digestion' would enable the mitigation of potentially high GHG emissions..."* and *"...emissions savings that have been prevented through the mitigation of a high impact activity within the counterfactual will likely be attributed to the emission inventories of sectors other than the energy sector".*

BEIS corroborates that *"the research completed during the secondment contributed to decisions that led to the promotion of generating biogas from waste materials within the RHI scheme"* **[G]**. Since reformation of the RHI policy the latest UK Energy Statistics (2019) confirm a **85% increase in UK heat generation from resources such as food and agricultural wastes** – a rise from **11.5 GWh in 2015** (22.3% total UK renewable heat) to **21.1 GWh in 2018** (31.7% of total).

Influencing the extension of funding for UK bioheat

Welfle was the academic member of the Heat Working Group (HWG) that developed the Renewable Energy Association's (R-E-A, a not-for-profit trade association) 2019 Bioenergy Strategy Reports **[I]**. Drawing on Welfle's experience working with DECC on the RHI scheme, and through highlighting UoM research **[2, 5]**, the leading recommendation for Government from the HWG was to act urgently to ensure continued support for UK renewable heat. Funding for the RHI had been due to end March 2021, and so *"a*

replacement scheme is required to secure a market for renewable heat technologies including biomass boilers, anaerobic digestion and biofuels" **[I]**.

This recommendation was included in the R-E-A's written evidence submitted to the House of Commons Science and Technology Committee. It was subsequently cited in the Committee's 'Report of Session 2017-2019': *"the Government must ensure that it avoids a repeat of the disruption caused by the closure of the feed-in tariff, and announces its plans for the successor scheme to the Renewable Heat Incentive no later than the Spring Statement 2020"* **[J]**. UK Government responded confirming that it is *"…committed to phasing out the installation of high carbon fossil fuel heating systems in off gas grid properties and will be consulting on options in early 2020"* **[J]**. In the 2020 Budget, HM Treasury committed **GBP10,000,000** to *"…extend the Domestic RHI in Great Britain until 31 March 2022"* and an additional **GBP100,000,000** for *"…introducing a new grant scheme from April 2022 to help households and small businesses invest in heat pumps and biomass boilers"* **[K]**.

5. Sources to corroborate the impact

[A] MacKay, D. & Stephenson, A. "Life Cycle Impacts of Biomass Electricity in 2020", DECC, 2014.
[B] Committee on Climate Change report: "Biomass in a Low-Carbon Economy", 2018.
[C] Testimonial letter from Head of Buildings, Industry and Bioenergy at the Committee on Climate Change, dated 5 November 2019
[D] Committee on Climate Change. "Bioenergy Call for Evidence Report", 2018.
[E] UK Department for BEIS report: "Clean Growth – Transforming Heating", 2018.
[F] EPSRC, "Decarbonising Heating and Cooling. Twentieth Report of Session 2017-19", 2019.
[G] Testimonial from Head of Bioenergy & Land Use Science, UK Department for Business, Energy & Industrial Strategy (BEIS), dated 31 October 2019
[H] UK Department for Energy & Climate Change report: "The Renewable Heat Incentive: A Reformed and Refocused Scheme. Proposed Reforms to the Existing Domestic and Non-Domestic Renewable Heat Incentive Schemes", 2016.
[I] Renewable Energy Association, "Bioenergy Strategy, Phase 1-3", 2019
[J] House of Commons Science and Technology Committee, "Clean Growth: Technologies for Meeting the UK's Emission Reduction Targets. Twentieth Report of Session 2017-19", and "Government Response to the Twentieth Report of Session 2017-19", both 2019.
[K] HM Treasury Budget 2020.